NASA TN D-440

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TECHNICAL NOTE
D-440

INVESTIGATION OF MINIMUM CORONA TYPE CURRENTS
FOR IGNITION OF AIRCRAFT FUEL VAPORS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON June 1960

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SUMMARY

Continuing an earlier study which had shown that lightning hazards definitely exist in relation to fuel tanks with direct lightning stroke currents burning holes in fuel tank walls, the present study established a much lower range of ignition currents that could present an indirect lightning hazard by corona and streamers in fuel vent areas under the influence of strong external thunderstorm charge fields.

Investigation of the minimum corona type currents required for ignition of aircraft fuel vapors has disclosed current magnitudes as low as 200 microamperes. The tests were conducted in still air inside a container, and therefore, cannot be directly extrapolated to possible ignition at fuel vents, but the tests do indicate a possible hazard.

Studies of minimum sparking currents versus time durations were made in relation to possible fuel vapor ignition from potentials induced from lightning discharge currents along the aircraft skin at discontinuities. Such pulses might be brought inside the aircraft along poorly bonded conductors into areas possibly having explosive fuel leak vapors present. Individual pulses less than 10 microsecond duration required currents of over one ampere for ignition of fuel vapor.

However, such sparking currents are in the range that may be encountered in lightning induced corona streamer pulses at fuel vent discontinuities. Therefore, consideration must be given to possibilities of flame propagation inside the fuel vent under actual flight conditions and to use of protective measures in relation to the indicated potential hazards.

INTRODUCTION

A general program has been started for the study of lightning hazards to aircraft fuel tanks, including the evaluation of the degree of hazard, completed earlier, and the development of protection methods, yet to be undertaken. An interim study has been completed (ref. 1) of possible fuel vapor ignition from static electrification and from induced sparking potentials caused by lightning to aircraft, and the results are presented in this report.

Static electrification on aircraft may be caused by charge accumulation from frictional contact of the aircraft with atmospheric particles. The potential of an aircraft in flight may rise to about 500, 000 volts from friction charging. The intense electric fields produce corona discharges on the aircraft extremities which must be considered as possible sources for ignition of fuel vapors. Friction charging on aircraft has been reported to increase with the cube and even higher powers of the aircraft speed. Thus the trend toward higher aircraft speeds must be expected to produce severe charging effects. Charging currents of 40 microamperes per square foot of frontal area have been measured on jet aircraft, indicating that total currents in excess of several milliamperes would be possible for a large jet aircraft. Therefore, the initial phases of the investigations were directed toward determining the static corona discharge currents required to ignite flammable aircraft fuel mixtures in relation to possible ignition at fuel vents.

Also, in relation to possible induced sparking potentials from lightning discharges in the aircraft skin, studies were made of the current magnitudes versus time duration required for igniting fuel vapors.

The skin of the modern all-metal aircraft provides a relatively excellent electromagnetic shield against the short duration transient components of the lightning discharge. Owing to the low resistance of the outer skin, which may run only a few milliohms from the tail to the nose of an aircraft, the long duration low magnitude stroke components against which the shielding is not effective can not build up significant potentials. For typical long duration components of several hundred amperes, less than a volt would be developed across the few milliohms resistance of the outer skin. However, there are points at which the metal skin fails to protect, such as at fuel vents where the propagation of ignited fuel vapors into the aircraft interior might be possible, or at control cables, hatches, navigation lights, de-icer heating wires, etc., where inductive sparking potentials or stroke energies could enter.

Thus, a study of the minimum corona discharge currents and also minimum spark ignition energies is important in relation to evaluating potential hazards from atmospheric electrical transients involving aircraft.

This investigation was carried out at the Lightning and Transients Research Institute under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

TEST PROCEDURE AND DISCUSSION

Minimum Corona Type Currents Required for Fuel Vapor Ignition

Studies of the minimum corona currents required for fuel vapor ignition were made using the test arrangement shown in figure 1. One quart sample fuel tanks were filled with fresh fuel to a depth of one-eighth inch and placed in the temperature controlled box for 30 to 45 minutes to allow a liquid-vapor equilibrium to be reached. The temperatures of the box, the liquid and the fuel vapor were then measured and the thermocouples were withdrawn as it had been found that sparking occurred to the thermocouples. Next, high voltage was fed to a corona point located in the container and the voltage and corresponding corona current were increased at a rate of about 10 microamperes per second until ignition occurred or until a maximum current of about 600 microamperes was reached without ignition. A long 50 megohm resistance was used in series with the corona point to assure that filter capacitor discharges did not occur. A new corona point was used for each test as it had been found that explosion burned the points sufficiently to affect the discharge rates. The corona point was located in a Teflon bushing and the length of the metal was minimized to reduce stray capacity and prevent capacitive sparks. The point capacity was measured to be about two micromicrofarads. The tests were checked with an oscillograph for observation of the discharge currents, and with a radio receiver to audibly detect any possible sparking. The oscillograph indicated typical corona pulses of about one-half milliampere magnitude lasting about 0.1 microsecond and the radio receiver indicated only typical corona noise.

The results of the tests are presented in the graphs of figure 2 and show that minimum corona currents of about 220 microamperes are required for ignition of the fuels tested which included aviation gasoline, JP-4, kerosene, RVP special fuel and Ram Jet fuel. The minimum ignition currents occurred approximately in the middle of the flammability range as might be expected. As it is known that corona currents off a single wick discharger on a modern propeller driven transport may easily exceed 200 microamperes, this information gives some cause for concern. The location and shape of an aircraft fuel vent would be of importance in relation to the degree of hazard. It should be emphasized that the above tests were made in still air inside a container and indicate only that corona currents of this magnitude are capable of igniting fuel vapors, not that such currents would necessarily ignite fuel vapors in a high speed windstream where the thermodynamics of the ignition mechanism might be considerably different.

However, it is obvious from the above tests that as there is a possibility of a serious potential hazard, there is therefore a need for investigation of various specific aircraft fuel vent installations.

Minimum Spark Ignition Currents and Time Durations

Lightning discharges to an all-metal aircraft, although effectively shielded from the interior by the all-metal skin, can induce voltages on conductors such as the control cables, navigation light wiring, de-icing heater wires, etc., which pass through the skin into the aircraft interior and studies have been made to determine the possibility of such potentials igniting fuel vapors. As induced potentials are related to current rates of change rather than magnitudes, they are expected to be of short duration corresponding to the steep current wave fronts on some type of lightning discharges, typically cloud to ground strokes, and therefore, current magnitudes versus time durations required to ignite fuel vapors were determined in these studies. Aviation gasoline was used for a fuel, for although it is less easy to obtain a known concentration than with gaseous fuels such as methane or ethane, the results are more directly applicable to the problem of fuel ignition in aircraft.

Earlier investigators have been concerned primarily with the energies required for ignition and considerable data exist on this subject, but for discharges described as capacitive or inductive, rather than in terms of current wave-shapes possible with modern oscillographic techniques. For correlation with earlier investigations, some tests were made to determine the minimum energies using the test arrangement shown in figure 3. Measured amounts of aviation gasoline were placed inside a quart container which had a spark gap located near the bottom. A variable condenser was adjusted to a given capacity using a Boonton Q meter for calibration. The Q meter was then disconnected after correction for meter lead capacities and the capacitor was charged to a given voltage after which it was discharged to the spark gap inside the fuel cell. The spark gap in the fuel cell consisted of two ball gaps spaced up to about 1/8 inch. For a given setting of the variable capacitor the charging voltage was lowered after each test until ignition no longer occurred and the minimum voltage for a given capacitor setting was recorded. After each test the fuel cell was aired to remove combustion products from the previous test, a new charge of fuel was placed inside the cell and the fresh fuel was allowed 15 to 45 seconds for evaporation before beginning the new test.

Using this test arrangement the values of minimum charge voltage for a given capacity were obtained and these values are presented in the graph of figure 4. As may be observed on the graph, the charging voltages varied from 16,000 volts for approximately 5 micromicrofarads to less than 7 kilovolts for 36 micromicrofarads, with $1/2\ CE^2$ from 0.64 to 0.88 millijoule.

The amount of fuel added to the fuel cell was approximately that required for a stoichiometric mixture and this value was arrived at by calculation and by experimental tests to determine maximum explosion pressures.

The preceding work is in agreement with other investigators' findings (ref. 2) that energies of the order of a millijoule concentrated in a short spark will ignite flammable fuel vapors. To relate the data to discharge transients dissipating only a portion of their energies in the flammable area, other measurable criteria than source energies must be used. Consequently a series of tests were devised relating fuel vapor ignition to current and time variations.

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The test arrangement for the study of spark ignition current-time variation is shown in figure 5. Measured amounts of aviation gasoline were placed in a quart container and after 30 to 45 seconds allowed for evaporation of the fuel, the mixture was ignited by a spark gap near the bottom of the container. The spark gap consisted of two 3 mil needle points spaced 1/16 inch apart, one grounded at the bottom of the container and one connected to the high voltage lead. The high voltage lead was connected through a control resistor to the storage capacitor and by selection of storage capacity, resistor magnitude, and charge voltage, discharges of various magnitudes and time durations could be obtained. The container was grounded through a current measuring resistance across which was connected the oscilloscope for monitoring of current waveshapes. The resistance was limited to about 1000 ohms to limit capacity errors possible with the high frequency discharge components. The discharges were essentially typical capacitor discharges with exponential current decay modified slightly by the nonlinear spark resistance and the stray spark gap capacity. Typical oscillograms replotted to equal scales for comparison are presented in figure 6. The results of the fuel ignition tests are presented in the graph of figure 7.

The time durations presented in the graph of figure 7 are the times "T" required for current decay to about one-third value and the currents shown are peak current values "I max" of the fundamental discharge waveshape. The solid line drawn approximately corresponding to the experimentally measured points gives an interesting criterion of "$I^2_{max}T$" being a constant which would correspond to a constant minimum ignition energy in the spark, if the spark resistance were constant. However, the spark resistance varies and would tend to be higher for the shorter time duration discharge providing higher energies which are apparently balanced by the lower effectiveness to be naturally expected of shorter duration sparks in producing ignition. A point corresponding to the value for an average corona current discharge, discussed in the previous section, is indicated in the lower right of the graph for comparison.

As may be seen in the graph of figure 7, ignition currents of over one ampere would be required for very short discharges of about 1 microsecond; whereas, for continuous average corona current, only about 200 microamperes are required. The above information, as pointed out previously, is important in evaluating hazards from possible high gradient induced corona and streamers near fuel vents and also from possible internal inductive voltage drop sparking which might ignite possible fuel leak vapors inside the aircraft.

CONCLUDING REMARKS

The first part of this study on lightning hazards to aircraft fuel tanks (ref. 1), carried out over the period from December 1954 to December 1956, showed that lightning hazards definitely exist in relation to fuel tanks with direct lightning stroke current burning holes in fuel tank walls.

The present report is essentially a limited supplementary study on minimum corona type currents that might cause fuel vapor ignition in fuel vent areas. This study established a much lower range of ignition currents that could present an indirect lightning hazard by corona and streamers in fuel vent areas under the influence of strong external thunderstorm charge fields.

Investigation of the minimum corona currents required for ignition of aircraft fuel vapors has disclosed current magnitudes as low as 200 microamperes, which being comparable to values measured in flight on static wick dischargers on domestic transport aircraft, indicate a possible hazard. The tests were conducted in still air inside a container, and therefore, cannot be directly extrapolated to possible ignition at fuel vents, but the tests do indicate a possible hazard.

Studies of minimum sparking currents versus time durations in relation to possible fuel vapor ignition, from potentials induced from lightning discharge currents along the aircraft skin at discontinuities, have shown that currents of over one ampere are required for ignition in less than 10 microseconds, in contrast to the average corona continuous currents with magnitudes of only about 200 microamperes. However, such currents are theoretically possible and might be troublesome when brought inside aircraft along poorly bonded conductors into areas possibly having explosive fuel leak vapors present.

Reference 1 states, and this should be emphasized, that the lightning hazard to fuel tanks presents a real problem requiring an extensive program of researches toward more adequate lightning protection than the present state of the art provides.

In addition to the work presented in this report, parallel supplementary (but as yet rather limited) interim lightning protection studies, and a review of incoming lightning strike reports lead to the following general comments:

(1) Probably every aircraft flying today could in certain circumstances, demonstrable in laboratory experiments, actually be exploded by some particularly oriented lightning discharge.

(2) Statistically, probabilities of lightning exploding aircraft are undoubtedly small; however, reliance on lack of past direct evidence of lighning having directly caused destruction of any specific aircraft, if repeatedly used as a weighting factor in analysis, can lead to self-perpetuating erroneous over-optimistic statistical conclusions.

(3) An aircraft contacted by a lightning discharge channel can be raised to voltages of the order of 100, 000, 000 volts leading to corona streamers, even in relatively shielded fuel vent configurations, with currents comparable to some of the fuel vapor igniting current characteristics of figure 7 of this report. Such currents would not necessarily leave any tangible evidence in the way of pitting.

While questions about supporting statistics on lightning hazards probabilities may continue to be debated, the present study strongly indicates that immediate consideration should be given to development and use of protective measures for fuel vents from lightning and streamer hazards. The two most promising approaches requiring further study appear to be the use of flame arresters (providing they can be made so as not to introduce icing problems) and the development of special vents less susceptible to lightning and streamer formation. These vents could either be metal with shielding to reduce streamer tendencies or possibly could be of non-conducting materials to reduce streamer initial formative currents.

REFERENCES

1. Robb, Hill, Newman and Stahmann; Lightning Hazards to Aircraft Fuel Tanks, NACA TN 4326, 1958.

2. Metzler, Allen J.: Minimum Spark Ignition Energies of 12 Pure Fuels at Atmospheric and Reduced Pressure, NACA RME53H31, 1953.

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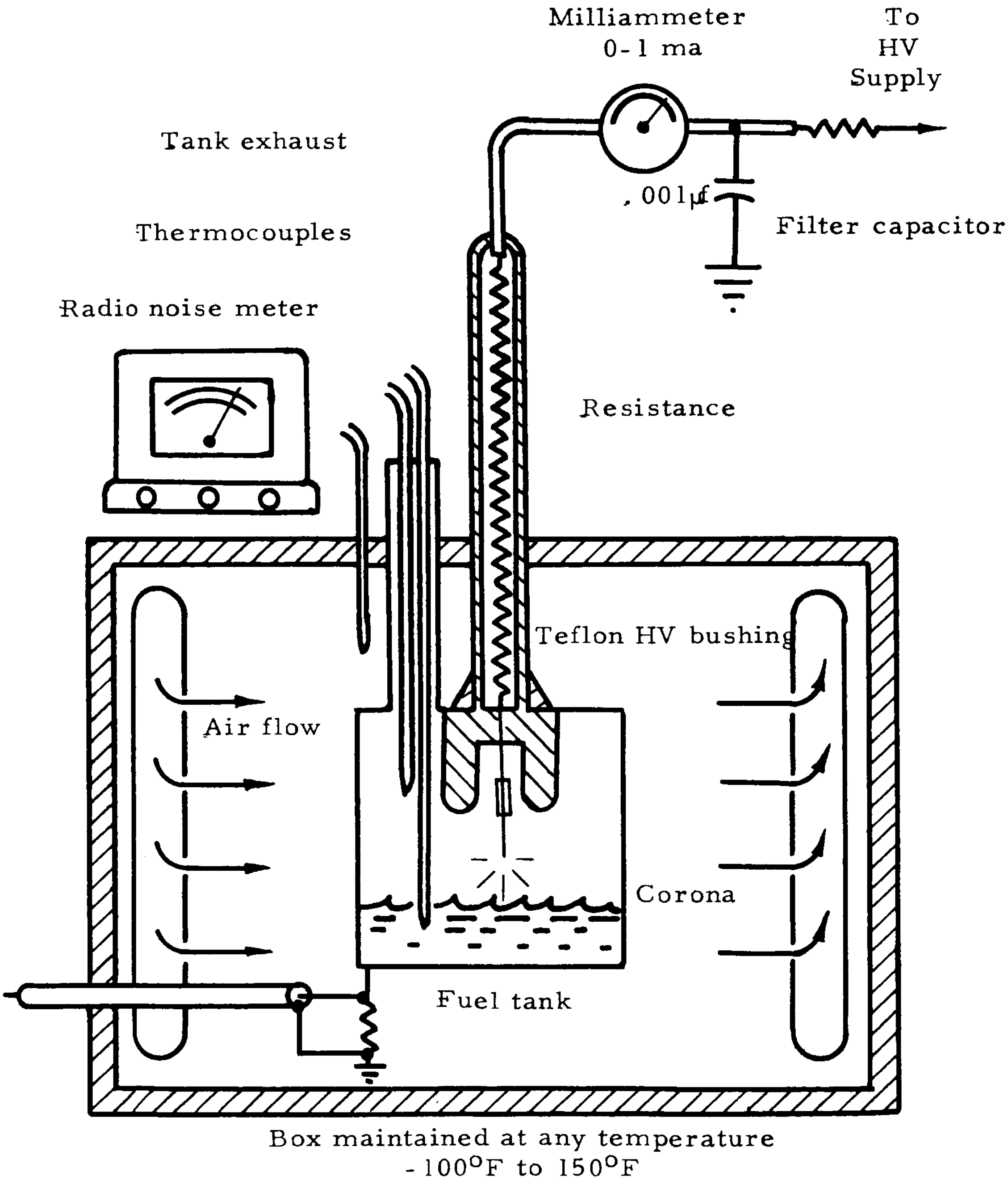

Figure 1. - Test arrangement for checking corona currents required to ignite flammable fuel vapor.

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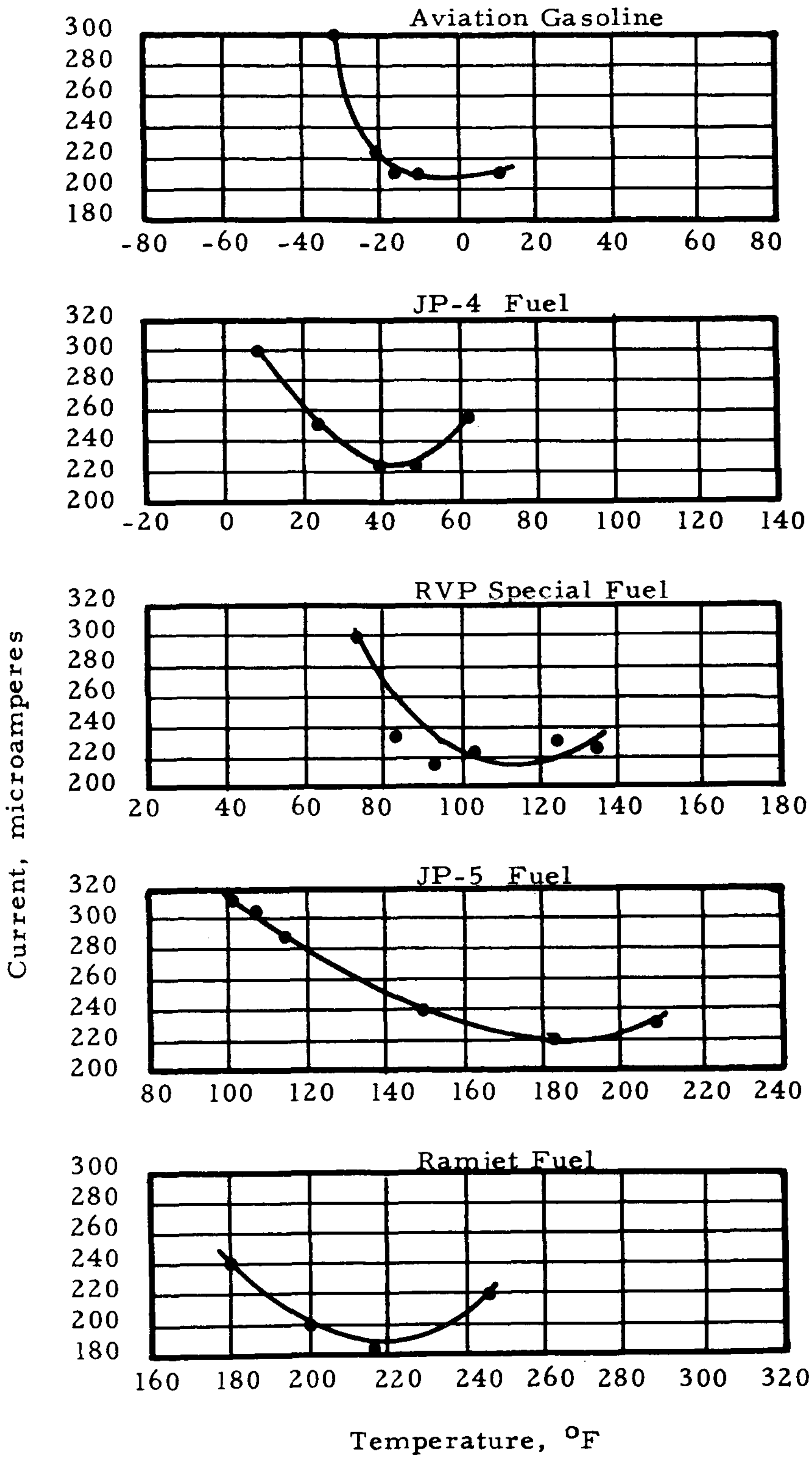

Figure 2. - Minimum corona currents required for ignition of various aircraft fuels.

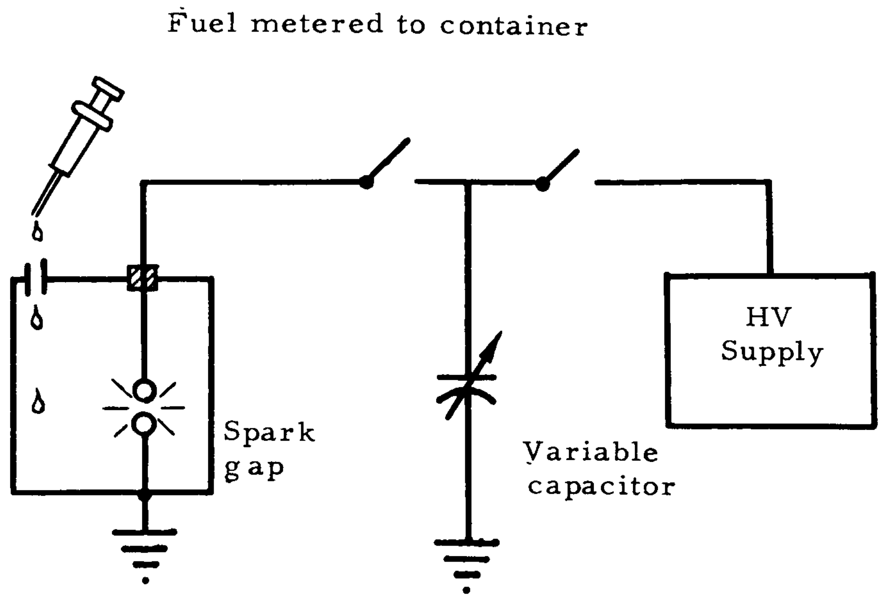

Figure 3. - Test arrangement for determining minimum capacity vs. voltage required for spark ignition of aviation gasoline.

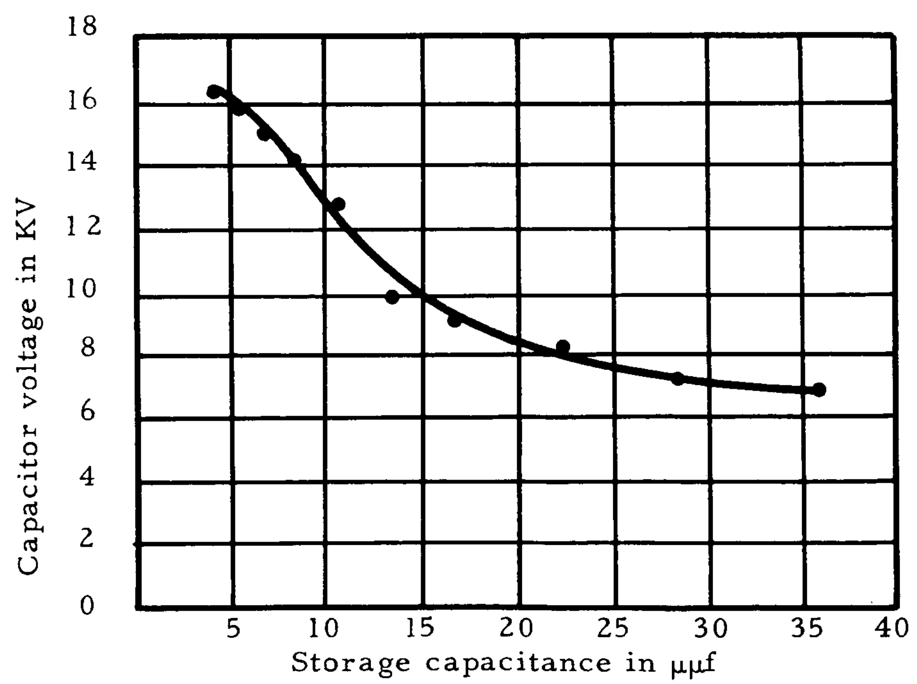

Figure 4. - Curve of minimum capacity vs. voltage required for spark ignition of aviation gasoline.

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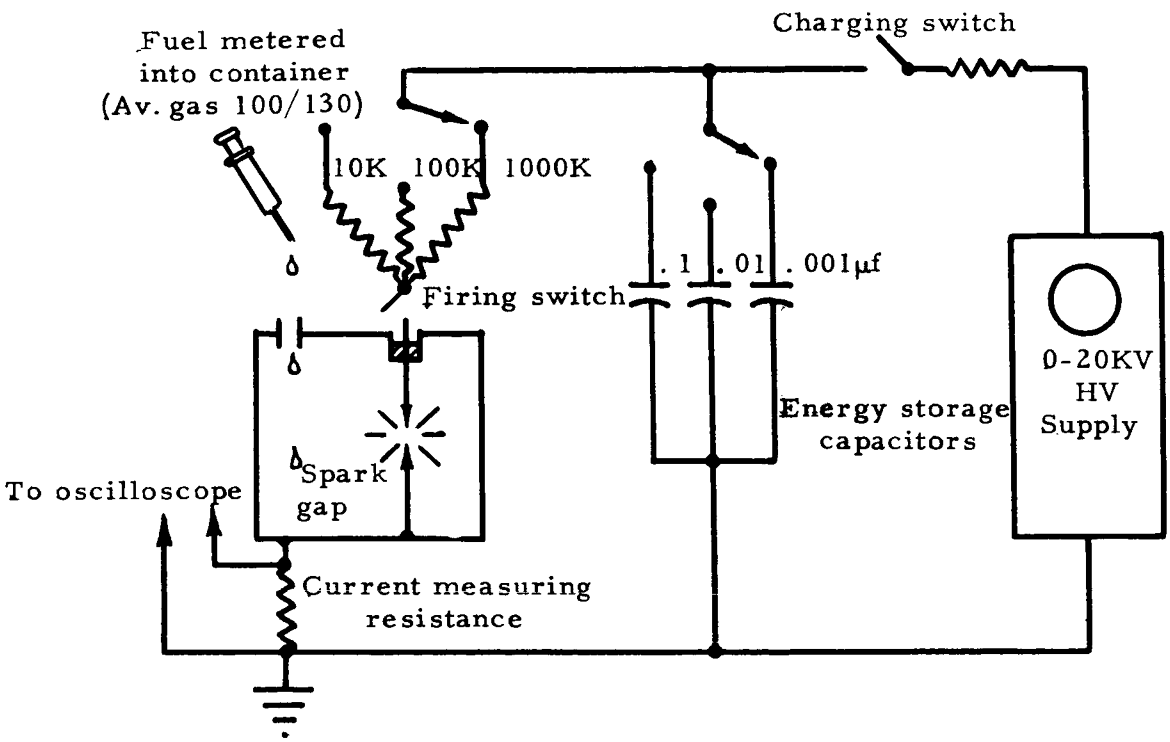

Figure 5. - Test arrangement for measurement of current amplitude and time duration required for fuel vapor ignition.

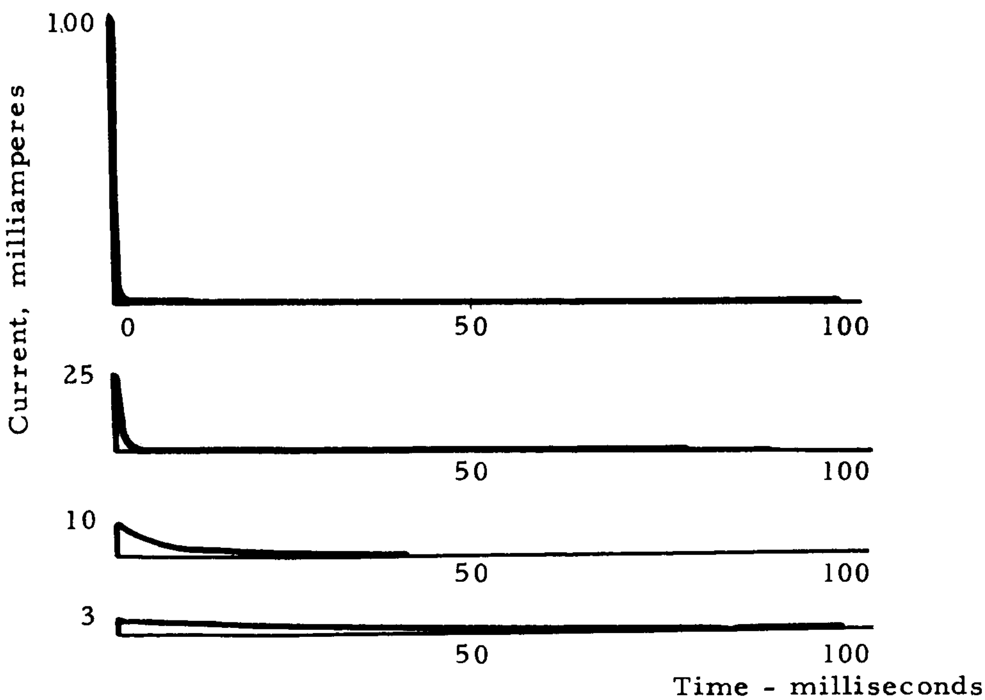

Figure 6. - Typical current wave shape oscillograms recorded, replotted above to equal scales, equally capable of fuel vapor ignition.

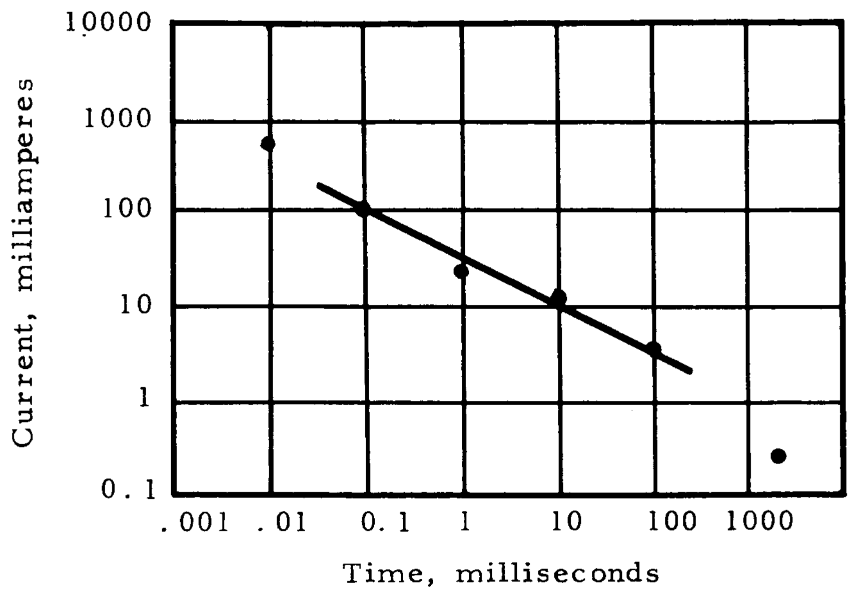

Figure 7. - Plot of minimum current vs. time duration for capacitor discharge ignition of aviation gasoline 100/130 grade.